Deep Ocean Water Upwelling Machine Using Density Current
-Creation of Fishing Ground and Absorption of CO2-

Kazuyuki Ouchi

Nakashima Propeller Co. Ltd.,

Eisen-iwamotocho Bldg. 2-8-8 Iwamotocho, Chiyoda-ku, Tokyo 101-0032 Japan

1. INTRODUCTION

In a stratified low latitude ocean area, the surface layer of the sea is warmed up by the sunlight and the high temperature air, and there is no vertical circulation between the warm surface layer and the cold bottom layer. Therefore, the sea of the low latitude area is always stratified with the temperature and density.

The mankind, wishing the sea of fertility, hopes the increase of primary production in the layer of sunlight where the photosynthesis can be done by the phytoplankton. But the primary production in the stratified sea area is very little, because the Deep Ocean Water (DOW) which includes very much nutrient-salt such as nitrogen and phosphorus etc. does not upwell to come in the layer of sunlight. Therefore, the low latitude sea area is called "the sea of desert", and the primary production is much less than that in middle or high latitude sea area. But we have some exceptions, for example in the sea of offshore Peru, a large amount of DOW upwelling is occurred by the steady wind, so that the sea area is one of the richest fishing ground in the world, and the water temperature in the surface is lower than another equatorial sea.

If we are able to make such a large amount of DOW upwelling artificially, we can expect to create and control the new fishing ground in "the sea of desert", and the increase of fish production is a very important issue toward the 21st century whose population will be in excess of 10 billion.

In addition of creation of the fishing ground, we can also expect the fixing carbon with photosynthesis done by the phytoplankton. But, to estimate the CO2 absorption from the air into the sea, we have to account also the amount of dissolved CO2 in the DOW in which the CO2 have been generated by bacteria in the course of decomposing the organic matter into the inorganic.[3]

In this paper, we propose the Deep Ocean Water upwelling machine which make "the sea of desert" into "the rich fishing ground" using the technology of density current diffusion and the ocean thermal energy conversion (OTEC), and we also report the feasibility study of the machine operation.

2. DENSITY CURRENT

The main feature of the DOW upwelling machine is utilizing a density current diffusion. Owing to this property, the machine is able to affect very wide sea area with very little energy. The outline of the density current is stated in this chapter.

In the liquid stratified with density, we can see the phenomenon that the fluid of a certain density tend to flow into the layer of identical density and then spread over great distances along the layer horizontally. This kind of current has long been known as a density current.

For example, it has been confirmed that when comparatively cold water from a river flows into a lake, the river water sinks for a while within the lake until it reaches the layer of equal density and then starts flowing, changing its direction of flow to horizontal, along the layer. Also in the vicinity of a river mouth where the water from the river enters the sea, high density sea water flows into the bottom layer of the river water during rising tide, while conversely during ebb tide, low density fresh water from the river spreads over the surface of the sea water. These phenomena are caused by the density currents, which can be observed through the nature.

Fig.1 shows a schematic drawing of a density current. Here, a liquid of a certain density enters a layer of identical density in form of a wedge, and as long as there is a supply of this liquid from behind, it moves forward, separating the liquid layers of higher and lower density like driving a wedge between them to create a density current.

In this way, gravity induces the density current through the difference of density potential between the upper and lower liquid layers. Thus the gravity provides the energy source for this movement, so that induction of this flow does not require any energy cost. This feature conceivably recommends an extensive use of this phenomenon.

3. DENSITY CURRENT GENERATOR

The prototype machine for generating the density current was researched and made by the authors.[1][2] The purpose of the machine is to make a density current and agitating the stratified sea water in the enclosed bay very calmly, and prevent the pollution such as the formation of low oxygen water, red tides, water blooms, etc.

Fig.2 shows a conceptual schema and general arrangement of the prototype density current generator. Waters from the surface and bottom layers of the sea

are sucked through bell-mouths and vertical pipes, and mixed up by the motor-driven impeller which has blades on both sides of the disc, then the mixed water is discharged horizontally toward all directions within the middle layer from the ring-nozzle formed in the pump casing, whereupon the water spreads through the layer as a density current. The electric power for driving the impeller motor is supplied by solar battery on the supporting pontoon.

The machine has been installed at Hasamaura of Gokasho Bay in Mie Prefecture Japan (about 100km southward from Nagoya City) since June 1997, and is working continuously for more than 2 years at the point of 15m water depth shown in Fig.3. This sea area is a enclosed bay with a length of approximately 2km and a width of about 500m. The total amount of sea water is approximately 12,000,000m³.

To achieve a turnover of this water during the summer in a period of about 100days, we designed the machine can create a mixed water of approximately 120,000m³/day. The mixture rate of surface and bottom layers was set to be 4:1, considering the temperature of the thermocline on the level of about 3m depth. Principal particulars of the machine is shown in Table 1, and the picture of the machine on operation is shown in Fig. 4.

4. INFLUENCE ON WATER ENVIRONMENT

The measurement of the flow distribution and the change of water quality around the machine was carried out in the summer of 1997.[1)2)] For this purpose, we stopped the machine for the 4 days from August 19 until August 23. The measurements without the machine running were made on August 23 and those during operation were made on August 26.

Fig.5 shows vertical distribution of the horizontal flow velocity at distances of 5m and 10m from the machine. We can know that the velocity of the discharged water quickly becomes slow down. Fig.6 shows the movement of tracer buoy thrown at the distance of 15m from the machine on the depth of 3m and 5m. These results reveals that the density current generated from the machine was running continuously and widely in a velocities of more than 30mm/s.

Regarding the water quality, Fig.7 shows the measurements of water temperature and turbidity made at 4 measuring points, distances of 5m, 50m, 100m and 300m from the machine. Fig.7 reveals a decrease of the surface layer temperature by 1 to 2 degrees C. and an increase of the water temperature within the intermediate layers by 1 to 2 degrees C. At the same time we could confirm that the thermocline, that had formed at a water depth of 2 to 4 m, had been eliminated.

Fig.7 also shows that turbidity reached a peak in the water depth of 3m while the machine was out of operation. After starting the machine this peak

disappeared and the water became more transparent. This phenomenon reveals that the machine eliminated the rich phytoplankton layer by making the certain flow field, so it is expected that the machine works as a red tide preventer.

5. DOW UPWELLING MACHINE

The deep ocean water (DOW) is the sea water located in the depth of more than about 400m, and has three major property, "nutrient", "clean", "cold". Its amount is estimated more than 90% of total water on the globe, therefore, DOW is a huge unused resource remained in 21st century. In this chapter, the study to design the DOW upwelling machine is reported.

The purpose of the machine is to make the layer of sunlight in the sea very nutrient, to increase phytoplankton, and to make a rich fishing ground. The technology of the density current generator and the OTEC as the engine of the machine is studied and we propose the DOW upwelling machine shown in Fig. 8.

Regarding the main hull, the concept of submerged spar buoy with tension legs is adopted. The structure above the sea surface should be minimized. Therefore, the side project areas and the water plane areas which are affected from strong winds and high waves respectively are small enough to maintain a stability of the machine even in case of big typhoon.

The heat exchanger such as the vaporizer and the condenser for the OTEC engine should be incorporated inside the upper and upwelling pipe and the hydrodynamic loss of the sea water flow should be minimum. New configuration and arrangement should be needed for the OTEC engine.

In Table 2, we propose the particulars of two different size DOW upwelling machines. One is a experiment scale having 4m diameter impeller for introduction and confirmation of the effects, and the other is a ultimate scale having 50m diameter impeller which can be manufactured only in the biggest shipbuilding facility for the super large tanker (VLCC).

6. FEASIBILITY STUDY

In this chapter, the effects such as increase of the primary production and fish production etc. by using the ultimate size DOW upwelling machine are studied in the case of setting up the machine in "the sea of desert".

In "the sea of desert ", we assume that the nutrient-salt density of DOW is 20 times of the surface water. The surface/DOW mixing rate of the machine is 2/1.

Then, the nutrient-salt density of the mixing water is ;

$$(1*2+20*1)/3 = 7.33$$

about 7 times of surface water.

The primary production of "the sea of desert" is assumed about 30 (gC/m²/year)[4)]. All mixed water is

assumed to be diffused within the layer of sunlight. The primary production per m^2 and the nutrient-salt density is assumed to be proportional.

Then, the increase of the primary production per m^2 is;

$$30*(7 - 1) = 180 \ (gC/m^2/year)$$

The thickness of the layer of sunlight is assumed 100m, and all the water within the layer is assumed to be replaced by the mixed water. And, the discharge capacity of the mixed water per year is;

$$90M \ (m^3/day)*365 = 32,850M \ (m^3/year).$$

Then, the area of fishing ground is;

$$32,850M / 100 = 330M \ (m^2 / year)$$

This area is the same as about 20km diameter circle. .
So that, the increase of the primary production by the machine is;

$$180* 330M*10^{-6} = 60K \ (ton \ C /year)$$

This means the carbon of 60,000 (ton C /year) is fixed by photosynthesis. From this result we expect that the machine is also very effective for the decrease CO_2 in the air through the absorption of CO_2 into the ocean. But we have to consider the DOW has dissolved CO_2 which has been accumulate by the bacteria in course of decompose the organic matter into inorganic.[3] This issue should be clarified quantitatively to estimate global warming by increase of CO_2 anyway.

Regarding the production of fishes, the reference should be made to J. Ryther's report.[5] Generally, the production efficiency of fishes in the upwelling sea area is very much higher than the other sea area such as coastal sea and open sea, because the size of phytoplankton is very big and the food chain steps is very short. From the Table 3,[5] we can know that the ratio between fish production and primary production in the upwelling sea area is;

$$(120*10^6) / (0.1*10^9) = 1.2$$

Then, the estimation of fish production in the new fishing ground using above ratio is ;

$$60K*1.2 = 72,000 \ (ton \ /year)$$
$$= 200 \ (ton \ /day \ )$$

And assuming the price of fish is US$2.00/kg, the estimation of income is ;

$$2.00*72,000*10^3 = 144,000,000 \ (US\$ / year)$$

The summary of the above study is shown in table 2.

The recent total amount of catching fishes in the world is less than 100 million tons. If we made 1,000 ultimate machine and operate in the equatorial ocean, $72K*1,000 = 72million$ (ton /year) fishes which are almost same amount of total catching fishes in the world is expected to be produced.

7. CONCLUSIONS

The conclusions of this paper are listed below.
1) Proposition of the concept design for the DOW upwelling machine which changes "the sea of desert" into "the rich fishing ground" was made.
2) The density current generator which is the origin of the DOW upwelling machine was introduced.

3) Outline particulars and specifications of the machine are established and general issue for key technologies such as density current diffusion, OTEC, stability of the machine, etc. was discussed.
4) From the feasibility study of the machine, it is known that the ultimate size machine can products fishes of 72,000ton/year, considering certain assumptions. This is very significant impact on the ocean environment.

REFERENCES

1) K.Ouchi, T.Yamatogi, K.Kobayashi, M.Nakamura : Research and Development of Density Current Generator, Journal of the Society of Naval Architects of Japan Vol.183, 1998.6.
2) K.Ouchi, T.Yamatogi, K.Kobayashi, M.Nakamura : Density Current Generator - A New Concept Machine for Agitating and Upwelling a Stratified Water Area - , Proceedings of Ocean Community Conference '98 Baltimore USA, 1998.11.
3) Y. Nozaki : Global Warming and the Oceans - The Role of Carbon Cycling - , University of Tokyo Press, 1993.
4) Berger et al : Productivity and Organic Carbon Flux Part 1, University of California San Diego SIO, 1987.
5) John Ryther : Photosynthesis and Fish Production in the Sea, Science Vol.166, 1969.

Table 1 Particulars of the Density Current Generator

Height(at High Tide)	16.4 m
Diameter (Maximum)	2.3 m
Diameter of Upper Pipe	0.8 m
Diameter of Lower Pipe	0.5 m
Weight of Upper Structure (in Air)	4.9 ton
Weight of Lower Structure(in Air)	2.9 ton
Weight of Anchor(in Air)	5.7 ton
Discharge Capacity (Maximum)	170,000 m3/day
Discharge Capacity (Normal)	120,000 m3/day
Ratio of Upper/Lower Suction Capacity	4／1
Rotatin Speed of Impeller(Normal)	50 rpm
Output of Motor(Normal)	5 kw
Outut of Solar Cell(Maximum)	12 kw

Table 2 Particulars and Effects of the Machine

Particulars	Experiment Scale	Ultimate Scale
Height from Sea Surface	10 m	10 m
Draft from Sea Surface	800 m	800 m
Diameter of Surface Suction Pipe	1.6 m	20 m
Diameter of Upwelling Pipe	1.3 m	16 m
Surface Suction Flow Rate	400,000 m3/day	60,000,000 m3/day
Upwelling Flow Rate	200,000 m3/day	30,000,000 m3/day
Discharge Flow Rate	600,000 m3/day	90,000,000 m3/day
Diameter of Impeller	4 m	50 m
Output of Impeller	100 kw	10,000 kw
Power Supply to Impeller	Turbine Drive by OTEC Rankine Cycle	
Mooring System	Submerged Spar-Buoy with 2 Tention Legs	
Material of Hull	Mild Steel with A/C and A/F Coating	
Effects		
Area of Fishing Ground	2.2 km2/year	330 km2/year
Primary Production in Carbon Weight	400 tonC/year	60,000 tonC/year
Fish Production in Wet Weight	480 ton/year	72,000 ton/year
Fish Production in US Dollars	$96,000./year	$144,000,000./year

Table 3 Fish Production in the Sea

	Primary Productions		Fish Productions	
	(tonC/year)	Ratio	(ton/year)	Ratio
Ocean Area	16.3*10^9	81.5	0.16*10^6	0.07
Coastal Area	3.6*10^9	18.0	120.00*10^6	49.97
Upwelling Area	0.1*10^9	0.5	120.00*10^6	49.97
Total	20.0*10^9	100.0	240.16*10^6	100.00

(J .Ryther : Science Vol.166, 1969.)

SURFACE
_____

LOW DENSITY

MIDDLE DENSITY

HIGH DENSITY

BOTTOM
_____
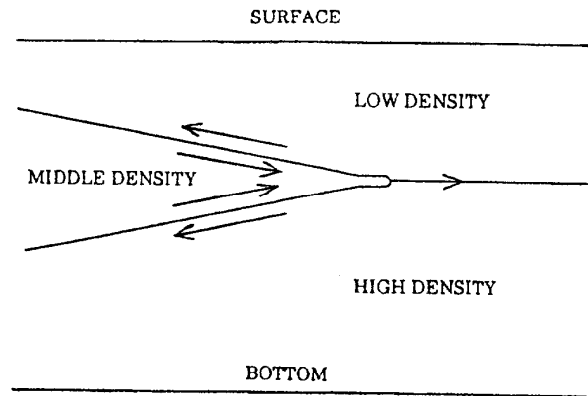
Fig.1   Schematic Drawing of Density Current

Motor
(M)

▽ Water Surface   Surface Current

Impeller   Density Current (Horizontal Diffusion)

Upper Impeller   Lower Impeller

Water of Poor Oxygen   Bottom Current

Sea Floor
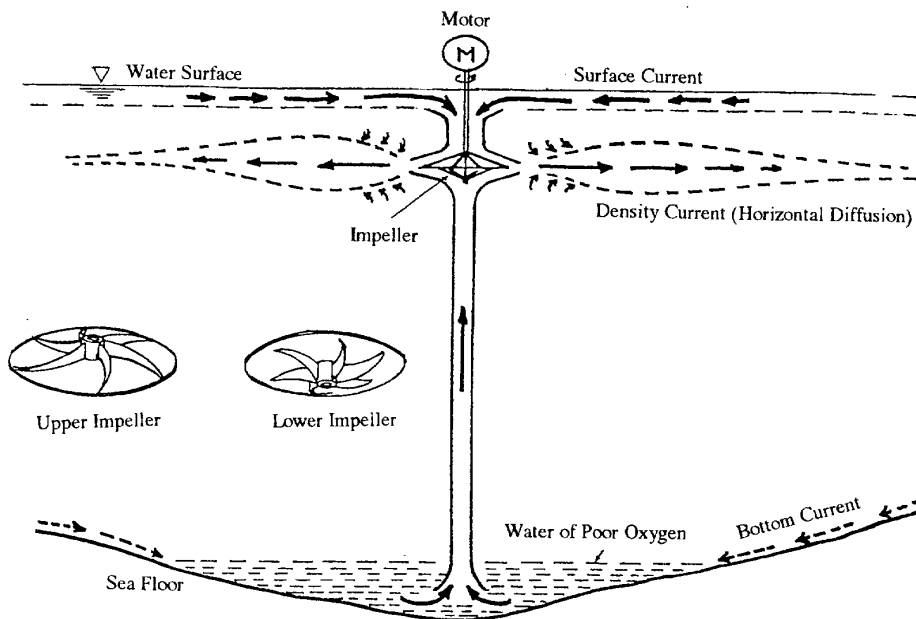
Fig.2   Concept of the Density Current Generator

Nansei-cho   Mie Prefecture

N

Gokasho Bay

0   600m

Hasamaura

The Machine

Fig.3   Map of Hasamaura Gokasyo Bay
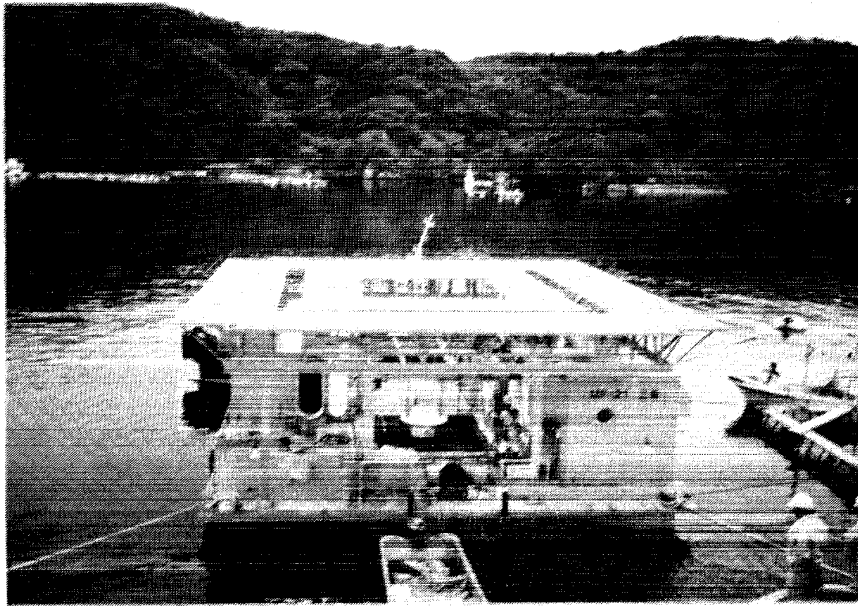
Fig.4   Picture of the Density Current Generator
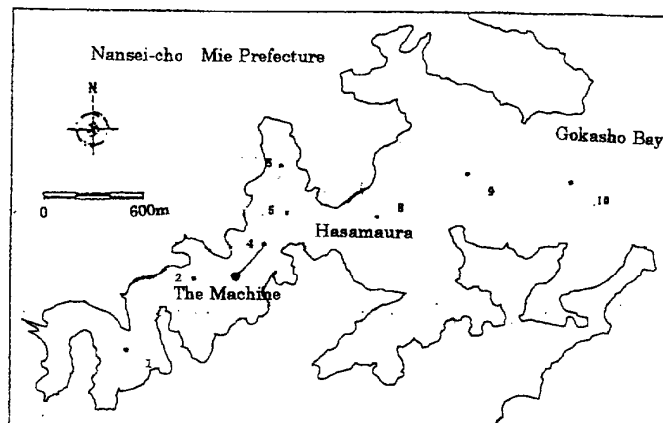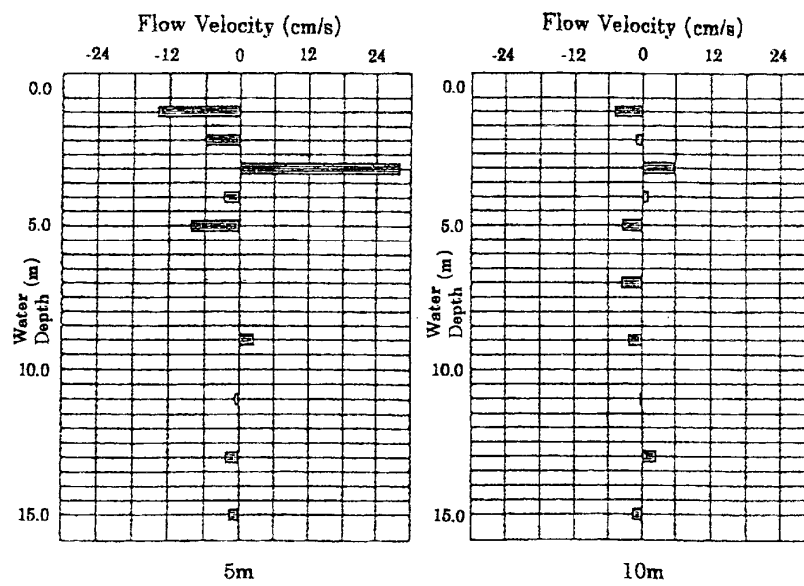

Fig.5   Vertical Distribution of Flow Velocity

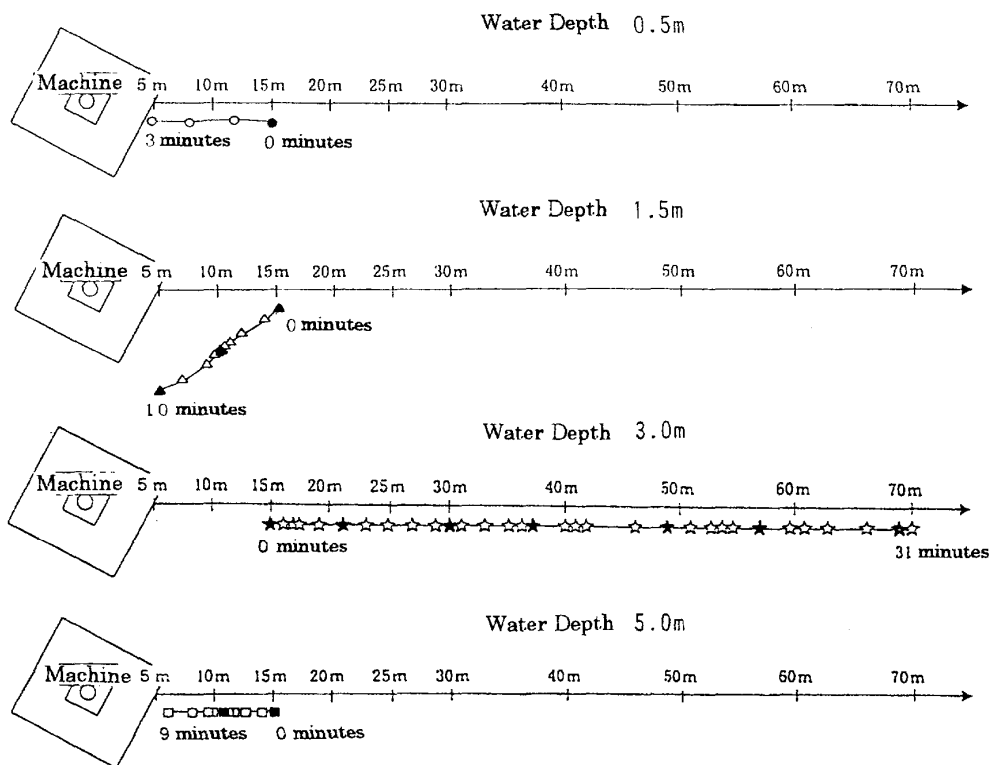## Water Depth 0.5m

Machine 5m 10m 15m 20m 25m 30m 40m 50m 60m 70m

3 minutes   0 minutes

Water Depth 1.5m

Machine 5m 10m 15m 20m 25m 30m 40m 50m 60m 70m

0 minutes

10 minutes

Water Depth 3.0m

Machine 5m 10m 15m 20m 25m 30m 40m 50m 60m 70m

0 minutes

31 minutes

Water Depth 5.0m

Machine 5m 10m 15m 20m 25m 30m 40m 50m 60m 70m

9 minutes   0 minutes

Fig.6   Tracer Buoy Movement by Density Current

Temperature (C)
20 22 24 26 28 30
Depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
5m

Temperature (C)
20 22 24 26 28 30
Depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
50m

Turbidity
0 1 2 3 4 5 6 7 8 9 10
Depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
5m

Turbidity
0 1 2 3 4 5 6 7 8 9 10
Depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
50m

→ No Machine
■ With Machine

Temperature (C)
20 22 24 26 28 30
Depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
100m

Temperature (C)
20 22 24 26 28 30
Depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
300m

Turbidity
0 1 2 3 4 5 6 7 8 9 10
Depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
100m

Turbidity
0 1 2 3 4 5 6 7 8 9 10
Depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
300m

→ No Machine
■ With Machine

Fig.7   Change of Water Quality

Water Depth

0m

Layer of Sunlight

100m

200m

300m

400m

500m

600m

700m

800m

Turbine

Shaft

Sea Surface

Surface Current

Vaporizer

Float Submerged

Density Current

Thermocline

Working Fluid Pump

Impeller

Condenser

Upwelling Pipe

Deep Sea Water

Bottom Current

Sinker

Chain

Sea Bottom

Water Temperature

25℃

20℃

15℃

10℃

5℃

Turbine
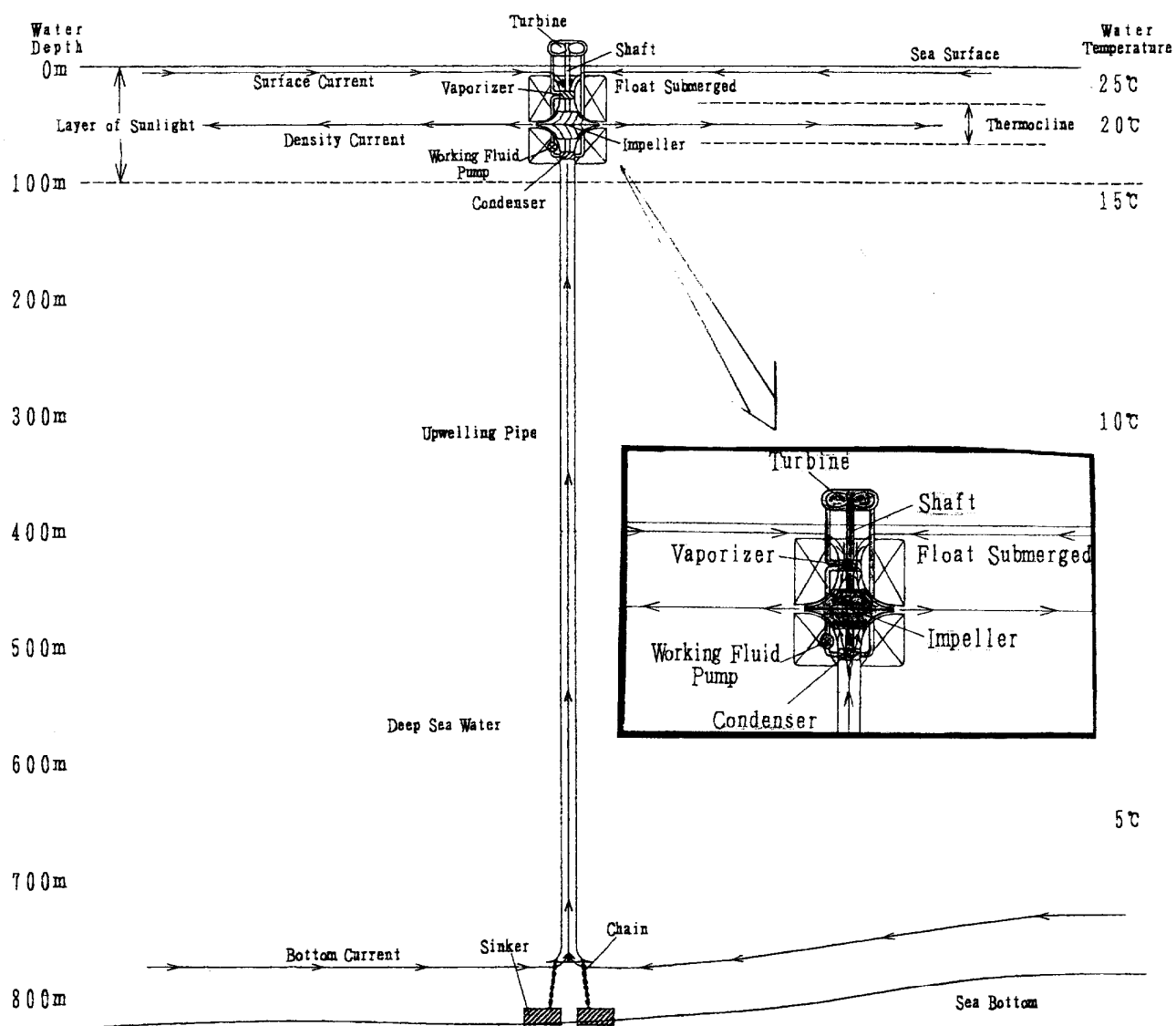
Shaft

Vaporizer

Float Submerged

Working Fluid Pump

Impeller

Condenser

Fig.8   Concept of the DOW Upwelling Machine